

APPLICATIONS OF MULTIBEAM SONAR SURVEYS IN THE U.S. ARMY CORPS OF ENGINEERS

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ABSTRACT

Multibeam sonars are shallow water instruments that provide full bottom coverage and are ideal for the inland waters and river operations covered by the U.S. Army Corps of Engineers (USACE). Recent advances in multibeam echo sounding coupled with increasing computing capabilities have led this agency to achieve higher efficiencies in performing its hydrographic surveying mission. The high resolution and accuracy of multibeam survey systems have enabled them to be used for dredge payment surveys in channel deepening operations where highly accurate digital terrain models (DTMs) are needed. Environments for hydrographic surveying range from muddy, low slope rivers with high concentrations of suspended particulate matter and very soft bottoms, to dynamic coastal areas and estuaries with rapidly changing water characteristics. These conditions will dictate which sonar frequency and swath width is best suited for a particular location. Included in this paper are examples from the Mississippi River area, Houston-Galveston Ship Channel, Panama Canal, and California. This wide range of conditions has justified the need for development of a low frequency multibeam transducer that will penetrate the unconsolidated sediments found in many rivers in the southeastern United States.

RÉSUMÉ

Les échosondeurs multifaisceaux pour petits fonds, offrant une couverture totale, sont des outils idéaux pour le sondage des eaux intérieures et des rivières couvertes par le U.S. Army Corps of Engineers (USACE). Les récents développements dans les technologies du multifaisceaux et des ordinateurs ont permis à notre organisation d'accroître significativement l'efficacité de nos opérations de sondages hydrographiques. L'accroissement de précision et de définition spatiale obtenu par l'utilisation des systèmes de balayage acoustique multifaisceaux offre en outre la possibilité de les employer dans des levés reliés aux opérations de dragage, là où la confection de modèles numériques de terrain précis est requise. Les conditions environnementales généralement rencontrées dans nos levés hydrographiques vont des rivières vaseuses, à pente douce et ayant de forte concentration d'alluvions en suspension, aux estuaires et autres zones côtières dynamiques, caractérisés par de rapides changements dans la colonne d'eau. Ces conditions environnementales vont dicter les paramètres d'acquisition à adopter, tels la fréquence d'émission et la largeur du balayage acoustique. Cet article présente des exemples concrets dans la rivière Mississippi, le chenal de navigation Houston-Galveston, le canal de Panama ainsi que des aires en Californie. Cette variété de conditions a justifié le besoin pour développer un nouveau transducteur multifaisceaux basse fréquence, qui pénétrera la couche de sédiment fluide qui tapisse le fond de la plupart des rivières du sud des États-Unis.

1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE) is responsible for the surveying, dredging, and maintenance of all the public harbors and ports in the Nation, including more than 40,000 km of navigable rivers and inland waters. In addition, there are several other areas of the world, such as the Panama Canal and U.S. Virgin Islands, where the USACE performs hydrographic surveying. Recent advances in remote sensing technologies, specifically multibeam

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echo sounding coupled with increasing computer processing capabilities, have led USACE to achieve higher efficiencies in performing its hydrographic surveying mission. Multibeam sonars have become smaller, lighter, more reliable, and cheaper. They have evolved from a deep water mapping tool to a shallow water instrument ideal for our inland waters and river operations. Several districts have installed these instruments on their survey boats and are gaining experience in using the full bottom coverage and backscatter information that the sonars provide. In order to take advantage of the latest hydrographic surveying technology, the U.S. Army Topographic Engineering Center (TEC) recently evaluated data from several systems for use in the different environments in which USACE operates. There is currently no system that meets all the requirements for multibeam surveying, based on the requirements of several districts and the wide range of conditions they encounter.

Environmental settings for hydrographic surveying range from muddy rivers with high concentrations of suspended particulates and very soft bottoms, to clear water harbors with hard bottoms, to dynamic coastal areas and estuaries with rapidly changing water characteristics. These conditions will dictate which sonar frequency and swath width is best suited for that location. Higher frequency multibeam sonars may not penetrate the soft layer of suspended mud or 'fluff' several inches thick on the bottom of some harbors thereby giving a shallower navigable depth than actually exists. Lower frequency sonars may not achieve the resolution needed for target identification in ship channels surveyed for obstructions. Surveying procedures also will vary depending on the water mass encountered. Estuaries with a well defined salt water wedge require frequent sound speed data corrections as well as data acquired in a manner that is efficient and reliable.

2.0 METHODS OF HYDROGRAPHIC SURVEYING

2.1 SINGLE BEAM ECHOSOUNDER

Single beam or vertical incidence echo sounders have been in use for more than 6 decades and have been used to collect the vast majority of existing bathymetric data. When a transducer transmits sound in the water column, the sound wave is reflected off the bottom, or by an object in the water column, and is then received by the transducer. By calculating the difference between the transmit and receive times, and multiplying by the speed of sound in the water, the depth of the seafloor or object in the water column can be measured. The physical properties of water, such as temperature and salinity, must be taken into account when converting to depth. The major constraint or assumption regarding these types of instruments is that the acoustic wave represents a vertical path between the transducer and the seafloor. This, of course, is not always a valid assumption and results in more limited coverage and resolution, but also makes them less prone to the error sources typically found in multibeam or swath systems (Mayer, 1996).

To have the most efficient sonar return, the outgoing beam must be focussed or directed to the area that must be ensonified. These directional beams will then limit the spherical spreading and loss associated with the sound wave. The combination of spherical spreading and absorption in the water column is referred to as attenuation, and is dependent on frequency. The higher the frequency the higher the attenuation, and it is a limiting factor in frequencies over 10 kHz.

Single beam echo sounders can be narrow or wide beam, depending on their intended use. Narrow beam sounders ensonify a small area dependent on the water depth and bottom topography. A small beam width that is directional is desirable. The beam width is inversely proportional to the dimensions of the transducer. These small transducers can be combined to cover a large area by mounting them on a boom suspended perpendicular to the vessel's course. This is known as a sweep system that is especially suited to USACE environments in shallow water

where full bottom coverage is required and where deeper draft vessels cannot operate. These are different from swath or multibeam systems that are a single instrument with many transducer elements.

2.2 MULTIBEAM ECHOSOUNDER

By combining many transducer elements into a single compact unit we can transmit and receive in a swath or fan shaped geometry and cover a larger area in one pass. The principles of beam forming/steering can be applied to a transducer with many elements to give a large bottom coverage with narrow beam widths. This swath or bottom coverage is typically two to five times the water depth and the resolution is enhanced by the narrow beams. Another advantage of the multibeam is that the transducer head can, in some cases, be rotated to give coverage in an area not directly under the vessel. This side-looking feature also is achieved by combining two transducer heads oriented at different angles.

As previously mentioned, the frequency of the transducer will determine the resolution and penetration through the water column. In general, the higher the frequency and bandwidth, the higher the resolution but lower the penetration. Most multibeam transducers used in USACE have a frequency of between 100 kHz and 450 kHz. Deep ocean transducers typically are lower frequency for greater penetration.

3.0 MULTIBEAM OPERATION

3.1 TYPES OF MULTIBEAM TRANSDUCERS

The two types of multibeam transducers are the Mills Cross and the arrayed or curved transducer whose beams can be steered. The different designs have advantages over single beam echo sounders, and with different frequencies can be used in different applications. Briefly, the Mills Cross transmits in one direction and receives orthogonal to it. Generally, the transmit elements are oriented parallel to the direction of the ship's track and the receive elements are oriented perpendicular to the direction of the ship's motion. The product (or intersection) of the two patterns results in a narrow beam, which is a desirable signal characteristic for the actual ensonified area.

Within the actual ensonified area it would be beneficial to steer or direct the beams. The two methods used to steer the beams are the time delay and Fast Fourier Transform (FFT). Essentially, the differential time delay involves applying a time delay to the actual input/output of each element in a transducer array. This results in the beam pattern being sensitive in certain angular sectors of the ensonified areas. The FFT, or more appropriately, the Discrete Fourier Transform (DFT) applies a transform on the spatial distribution of instantaneous signals received at each element across the array (Hughes Clark, 1996). There is a distinct spatial frequency in the instantaneous signal across the array face where a wave train intersects the front of a line array. One can separate out the different spatial frequencies by performing a DFT on the signals across the array, thus separates the energy to different angular sectors. This beam steering can be used to direct the beam at an arbitrary angle below the array. This helps in the compensation for motion such as vessel pitch.

4.0 SURVEYING ENVIRONMENTS

USACE conducts hydrographic surveys in various environments. These include surveys for harbors and ports, breakwaters, condition surveys, river flooding, dredging, estuaries, locks and dams, underwater target identification, and revetments. Since the advent of multibeam sonar and the increasing performance of personal computers, the amount of data collected has increased dramatically. This performance, in addition to integration with GIS, has made the Federal Government in general, and USACE in particular, the largest user of multibeam in the Nation.

4.1 MISSISSIPPI RIVER

The Mississippi River floods of 1993 did enormous amounts of damage. Since the technology was new at that time, USACE did not have any operating multibeam systems in the districts. Several private contractors had experience in multibeam operations and USACE contracted them for performing hydrographic surveys in several flooded areas on the Mississippi River.

4.1.1 Fountain Creek Lower Breach

The levees of the river were breached in several areas causing widespread flooding of the surrounding farms and towns. Figure 1 shows a levee break in the river south of St. Louis, MO. A small creek, Fountain Creek, flows into the Mississippi River to the west and is surrounded by levees. The upper levee is breached at two locations and a new breach is beginning to form between the two. Data were collected on the north side of the levee where trees are located. The contractor was able to use the 190 degree surveying capability of the multibeam transducer to collect data there.

4.1.2 Lock and Dam 25

There are many locks and dams on the Mississippi River that also were flooded. Lock and Dam 25 (not shown) had floodgates fully opened and water continued to cascade around the entire dam. A survey was made of the river in this vicinity since a boat was the only means to reach these sites. This lock and dam was surveyed by C&C Technologies, Inc., during the time flooding was at record levels. The north side of the dam was mapped with the vessel "crabbing" sideways and the bow pointing into the heavy current. When the north side was completed, the vessel "shot the rapids" and surveyed the south side of the dam.

4.1.3 Dam 27

This dam, at Mississippi River Mile 190.2, is a low water dam north of St. Louis (figure not shown). This also was surveyed at the flood's crest and shows two large water intake "houses" near the center of the river north of the dam. These houses were once living quarters for personnel who monitored the accompanying sluices during icy winters. Also shown is a buried intake line that extends to the western bank from one of these houses.

4.1.4 Dogtooth Bend

In sharp bends of rivers, the current velocity increases which, in many cases, causes erosion of the river bank. In order to deflect the current, thus reduce erosion, there are submerged walls, called bend way weirs, that essentially act as deflectors of the current. A multibeam survey of a sharp bend near St. Louis, MO shows several bendway weirs (Figure 2). Although some of these weirs were supposed to have been removed several years ago, and repositioned, the survey revealed that many had not. The vertical exaggeration is approximately five times on this display.

4.2 NEW YORK HARBOR

Dredging is the largest budgeted item in USACE. Hundreds of millions of dollars are spent on dredging and dredging operations each year in order for our Nation's harbors to remain commercially active. Multibeam sonar surveys can be used as dredge payment surveys in many areas where total bottom coverage is desired for a more accurate dredged volume. New York/New Jersey Harbor is an area that was used as a demonstration for multibeam surveys in dredged areas. Kill Van Kull (Figure 3) is a channel cut through hard bedrock separating Staten Island from New Jersey. In order to maintain this channel, expensive rock cutting dredges must be used in this area. The target depth is 42 feet, and areas above 40 feet are easily seen by the light colors. These areas are potential hazards to navigation and may have been missed by single beam sonars.

4.3 SAVANNAH RIVER

Locks and dams on the Savannah River also were surveyed to monitor the scour downstream of the dam. When floodgates are open there is potential for erosion and scour because of the high velocity and volume of the water. ARC Surveying and Mapping, Inc., performed a survey to determine baseline elevations in the area of the dam. Two large scour areas are clearly shown downstream of the dam. These data are used to then model the flow through the dam to prevent more serious erosion.

4.4 HOUSTON/GALVESTON SHIP CHANNEL

Recently, the Galveston District of USACE tested several multibeam systems for potential purchase. One of their criteria for purchasing a system was very good agreement between their single beam data and any multibeam data acquired. Shown in Figure 4 is a test of the Odom Echoscan multibeam compared to the single beam. Since many districts use single beam data to calculate volumes with the average end area method, a comparison of the cross sections to the multibeam, taken at any orientation, would reveal any errors in the calculations.

4.5 PANAMA CANAL

In 1995, the Panama Canal Commission requested that a multibeam survey be performed in the Panama Canal. These data will be used for construction planning, dredging, and navigational purposes by the Commission. With the higher resolution and full bottom coverage, the survey provided much needed data that could not be obtained with conventional single beam echo sounders. Figure 5 shows the northern edge of Gatun Lake and the canal itself. The dredging cuts are clearly visible as are the submerged railroad. Also noted is a submerged wreck and the old Indian trail built before the lake was flooded by Gatun Dam. This type of data had never been collected in this area.

4.6 LONG BEACH HARBOR

By combining multibeam sonar data with either lidar or other laser topographic terrain data, we can obtain a full above and below water digital terrain model (DTM) of an area of interest (Figure 6). This was achieved in 1993 in Long Beach Harbor in southern California. The breakwaters in this area were surveyed by multibeam sonar because of its side looking capabilities.

A breakwater in Long Beach with the lighthouse at the end reveals individual rocks used to construct the breakwater. These rocks sometimes will roll off the structure and into the channel. Here, multibeam sonar can locate them with its full bottom coverage.

In addition to these areas, USACE has used multibeam sonar to survey the Great Lakes, Long Island Sound, Ocean City Beach, MD and the U.S. Virgin Islands after the destruction caused by Hurricane Marilyn in 1995.

5.0 CONCLUSIONS

Clearly, multibeam sonar surveys are a vast improvement over single beam surveys because of their full bottom coverage, high accuracy, and increasing ease of use. In addition, the transducers can rotate to gather data off the side of the vessel or can be combined to cover 180 degrees in the vertical dimension to provide coverage in narrow channels. The backscatter or signal strength data from the sonar also can give information on details that could be missed with conventional single beam sonar. By changing the illumination and viewing angle these data can reveal structures and natural features not observed with older technology.

Currently, plans are to incorporate multibeam sonar surveys into USACE districts to a greater extent. This includes using multibeam sonars for dredge payment surveys and condition and revetment surveys. As more districts use these instruments they will become more efficient, and save time and money by providing timely hydrographic surveys of our Nations waterways.

6.0 REFERENCES

Clark, J. E. Hughes, "Swath Sonar Concepts." *USACE Coastal Multibeam Training Short Course*, from the Advanced Hydrographic Surveying Workshop, Mobile, AL, 18-22 March 1996.

Mayer, L., "Single Beam Echo Sounders and Sweep Systems." *USACE Coastal Multibeam Training Short Course*, from the Advanced Hydrographic Surveying Workshop, Mobile, AL 18-22 March 1996.

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FIGURES

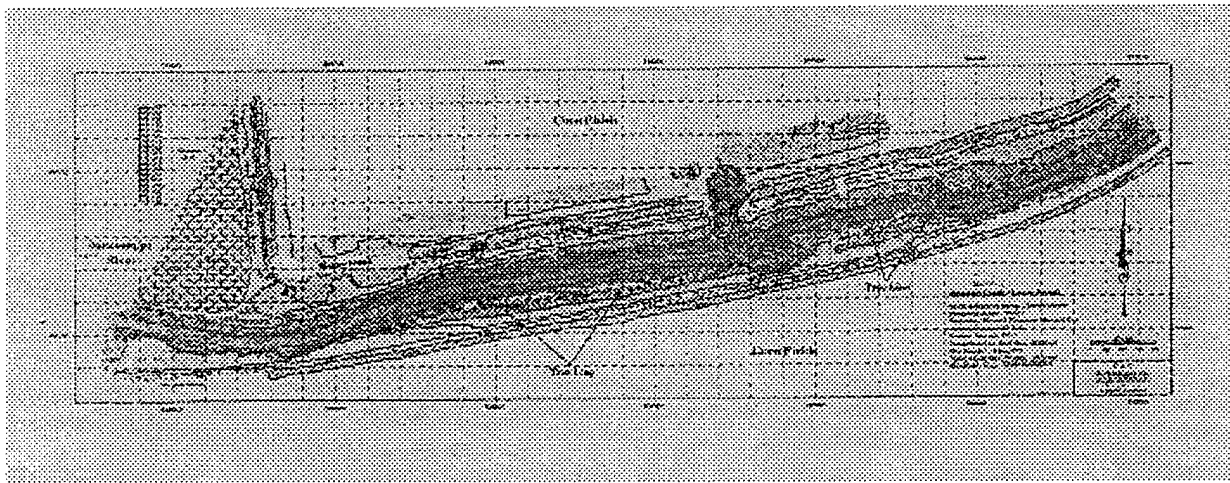


Figure 1. Fountain Creek Lower Branch Showing Levee Break
(Courtesy of C&C Technologies, Inc.)

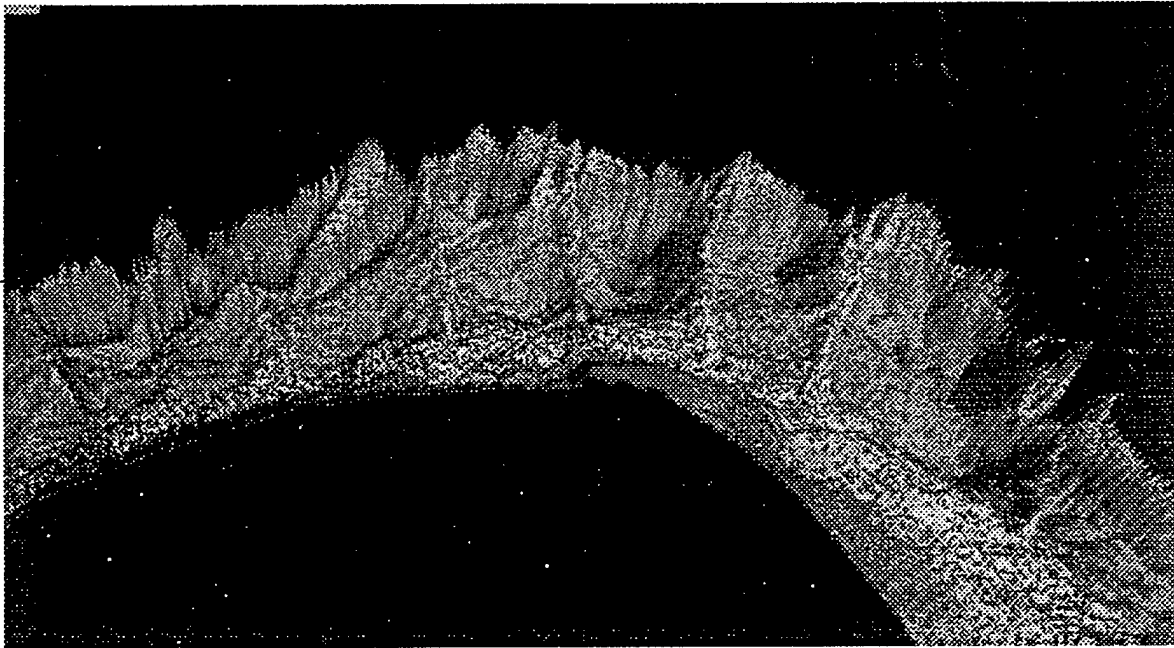


Figure 2. Dogtooth Bend Showing Bendway Weirs

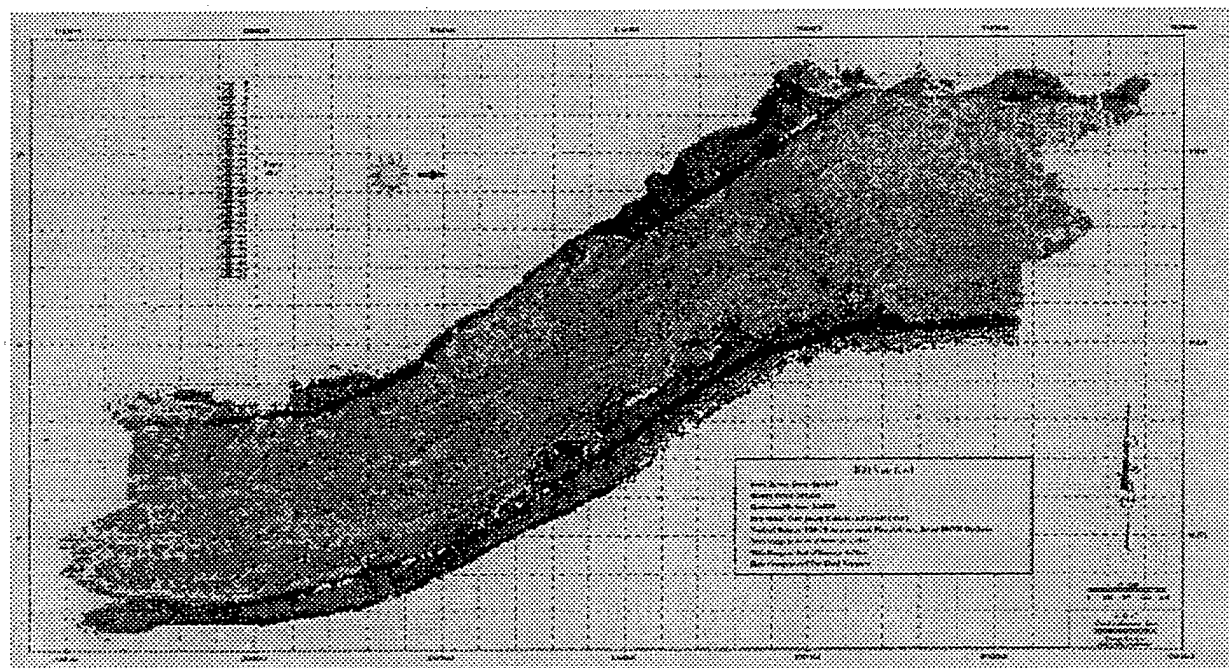
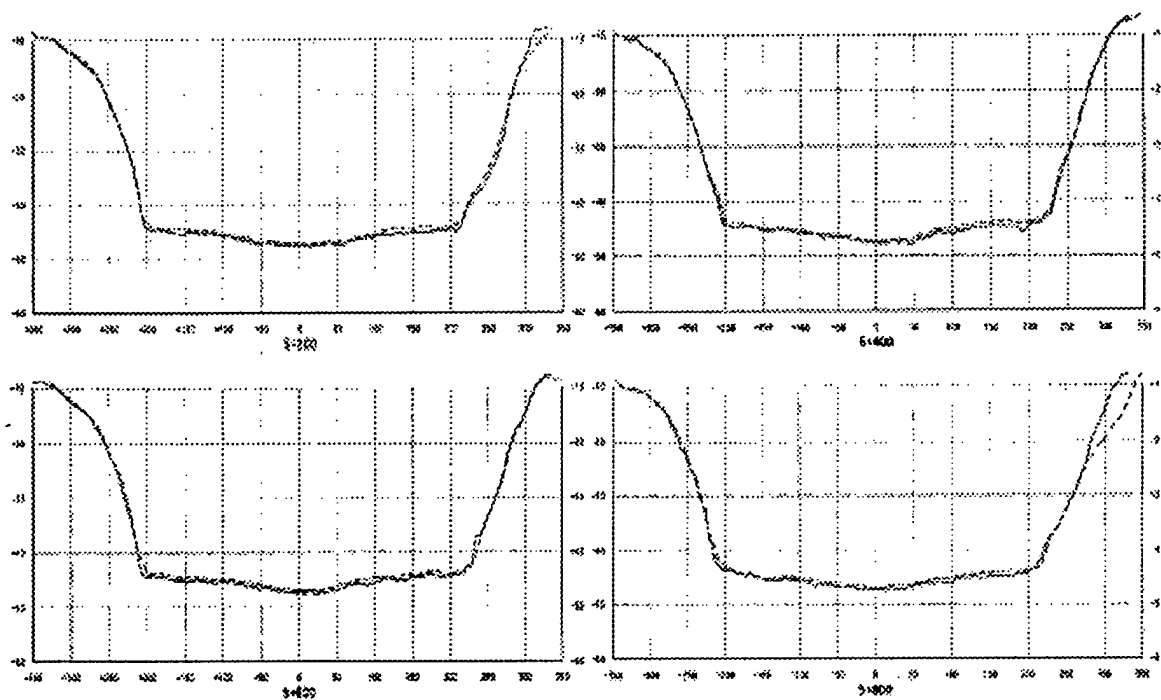
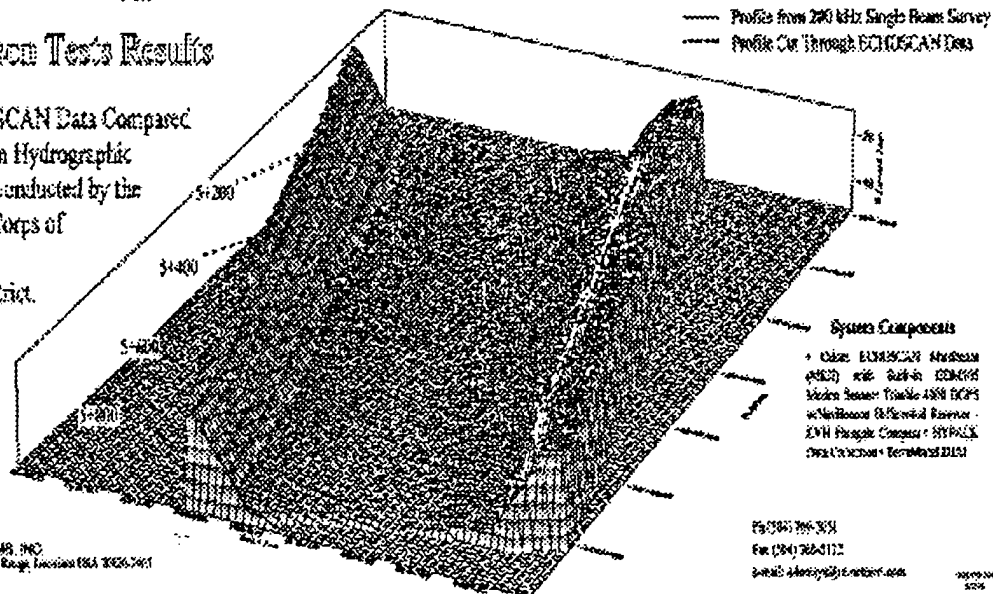


Figure 3. Kill Van Kull Channel (Courtesy of C&C Technologies, Inc.)



Comparison Tests Results

Odom ECHOSCAN Data Compared
to Single Beam Hydrographic
Survey. Test conducted by the
U.S. ARMY Corps of
Engineers,
Galveston District.



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Figure 4. Comparison of Single Beam and Multibeam Sonar in Houston/Galveston Ship Channel
(Courtesy of Odom Hydrographic Systems, Inc.)

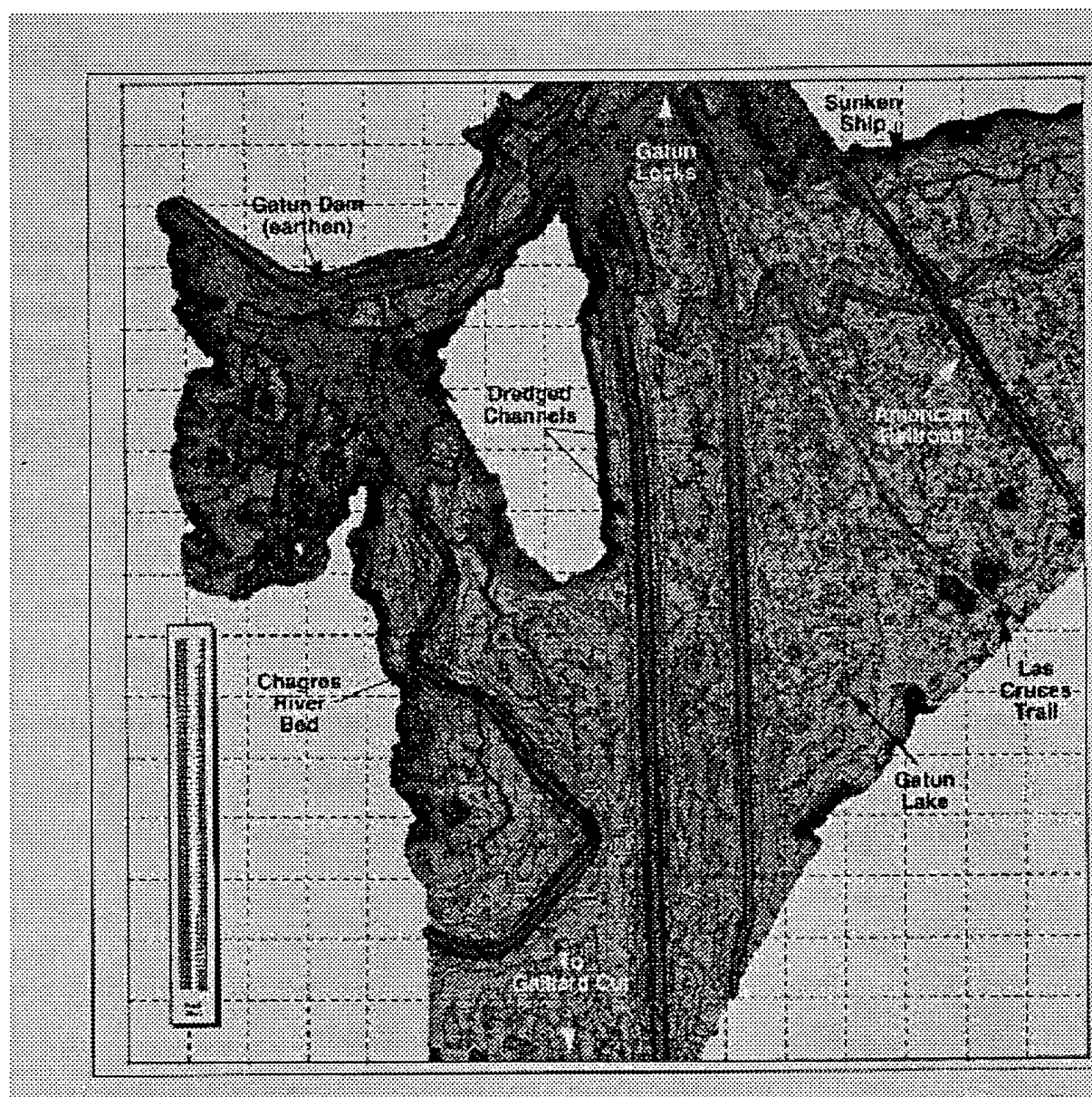


Figure 5. Multibeam Sonar Survey of Panama Canal (Courtesy of C&C Technologies, Inc.)

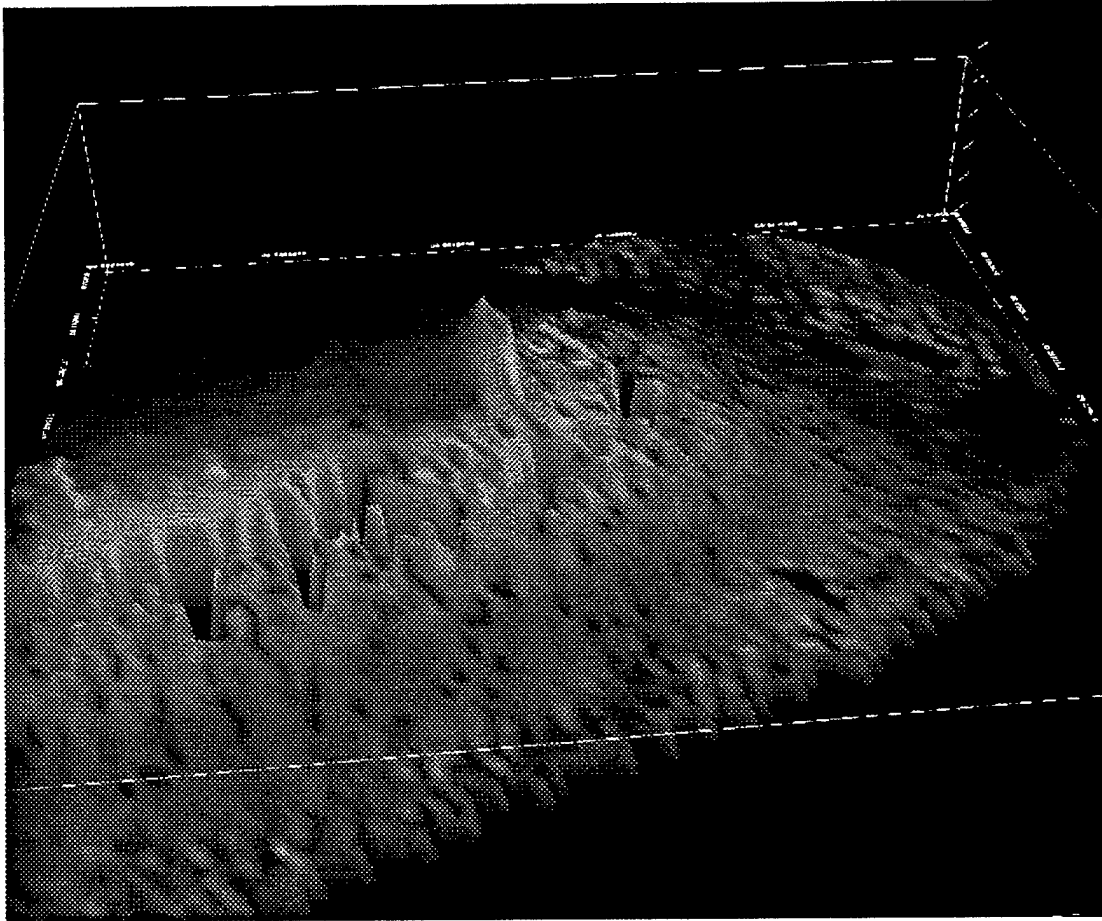


Figure 6. Multibeam sonar and lidar data showing lighthouse and breakwater at Long Beach Harbor, CA.